Can Self-Reported Tolerance of Exercise Intensity Play a Role in Exercise Testing?

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ABSTRACT

EKKEKAKIS, P., E. LIND, E. E. HALL, and S. J. PETRUZZELLO. Can Self-Reported Tolerance of Exercise Intensity Play a Role in Exercise Testing? *Med. Sci. Sports Exerc.*, Vol. 39, No. 7, pp. 1193–1199, 2007. **Introduction/Purpose:** To examine the relationship between self-reported tolerance of exercise intensity, measured by the Preference for and Tolerance of Exercise Intensity Questionnaire, and the amount of time individuals persevered during incremental treadmill tests to volitional fatigue beyond the point at which they had reached their ventilatory threshold. **Methods:** The participants in study 1 were college age and physically active (14 women, 16 men). The participants in study 2 were 24 middle-aged women who were healthy but sedentary. **Results:** Tolerance was related to the duration after the ventilatory threshold, and this relationship remained after age, body mass index, and self-reported frequency and duration of habitual physical activity (study 1) or after age, body mass index, and maximal aerobic capacity (study 2) had been taken into account. **Conclusion:** Self-reports of exercise intensity tolerance might account for variability in the extent to which individuals persevere during exercise tests. Identifying individuals predisposed to under- or overexertion could be of value in exercise testing and prescription.

Key Words: PERSONALITY, PREFERENCE, PHYSICAL ACTIVITY, VENTILATORY THRESHOLD

Exercise tolerance tests are commonly used in clinical practice on the basis of evidence that a higher level of exercise tolerance is reliably associated with reduced cardiovascular and all-cause mortality, independently of other risk factors. For example, each increase of one metabolic equivalent (MET; 3.5 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) in exercise tolerance, roughly corresponding to one additional minute of exercise time, has been found to be associated with a 12% decrease in mortality risk among men referred for exercise testing (15) and a 17% decrease in mortality risk among asymptomatic women (9). However, the diagnostic and prognostic value of exercise tolerance tests could be influenced by the fact that, in most cases, the tests are terminated because of subjective symptoms such as leg fatigue, an overall sense of exhaustion, breathlessness, and pain in the leg muscles, joints, or back.

The subjectivity inherent in these symptoms is consistent with findings that different individuals choose to terminate exercise tolerance tests at various distances from the level that their actual physiological capacity could have permitted (3). For example, in a large cohort of asymptomatic women, the range in the percentage of age-predicted exercise capacity achieved during a symptom-limited treadmill test extended from 20 to 150% (8).

Thus, there has been renewed interest lately into the role of the brain in determining exercise tolerance and endurance capacity (12,13). However, although authors often invoke such constructs as "motivation" or "effort," the psychological factors that might account for interindividual variability in exercise tolerance remain poorly understood. Certain biologically rooted personality traits, such as extraversion, have been theorized to relate to tolerance of sensory stimulation in the noxious range. However, the few studies involving exercise and other bodily stimuli have yielded equivocal results (6). These inconsistencies might be attributable to the fact that the standard self-report measures of these traits focus almost entirely on responses to social stimuli while making little or no reference to responses to bodily stimuli, such as those generated during vigorous exercise. However, exteroceptive (i.e., visual, auditory) and interoceptive sensory systems are quite different in terms of their anatomical and physiological design features, making extrapolations from one domain to the other imprudent.

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On the basis of this argument, the Preference for and Tolerance of the Intensity of Exercise Questionnaire (PRETIE-Q) was developed as a measure of individual differences in responses to bodily stimulation generated during exercise (6). The 16 items of this questionnaire are grouped in two oblique (i.e., partially correlated) factors, one assessing preference for exercise intensity and the other tolerance of exercise intensity. These factors were conceptualized as biologically rooted traits. The rationale for this conceptualization was based on the observation that large, temporally consistent interindividual variability in preference for and tolerance of exercise intensity, beyond what can be accounted for by somatometric and physiological differences, is observed not only in humans but also in species as diverse as mice (4) and lizards (14). Furthermore, the high 3- and 4-month test–retest reliability of the scales of the PRETIE-Q also suggests that these constructs represent stable traits (6). Tolerance of exercise intensity, in particular, was defined as a trait that influences one's ability to continue exercising at levels of intensity associated with discomfort or displeasure (6). An initial validation study showed that the tolerance scale, but not the preference scale, accounted for significant portions of the variability (29% at minute 12; 16% at minute 15) in ratings of pleasure–displeasure during a 15-min treadmill run at an intensity 10% $\dot{V}O_{2max}$ above the ventilatory threshold (6). The purpose of the present studies was to examine whether self-reported tolerance for exercise intensity, as assessed by the PRETIE-Q, could account for significant portions of the variability in the amount of time individuals persisted on incremental treadmill tests beyond the point at which they had reached their ventilatory thresholds (VT). This operational definition of tolerance was chosen because the VT has been found to be the level of intensity beyond which significant declines in pleasure begin to occur during incremental exercise tests (5,11). Two studies were conducted—one involving a young, physically active sample, and one involving a middle-aged, sedentary sample—to examine the consistency of the findings across diverse populations.

TABLE 1. Descriptive statistics (mean ± SD) for the demographic, somatometric, and physiological characteristics of the participants.

	Study 1		Study 2
	Women (*N* = 14)	**Men (*N* = 16)**	**Women (*N* = 24)**
Age (yr)	21.21 ± 2.04	21.50 ± 2.45	43.29 ± 4.80
Height (cm)	167.28 ± 9.14	182.17 ± 5.00	166.48 ± 5.92
Body mass (kg)	60.59 ± 6.63	78.50 ± 9.20	77.70 ± 16.80
Body mass index ($m \cdot kg^{-2}$)	21.69 ± 2.15	23.63 ± 2.42	27.96 ± 6.12
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	47.71 ± 7.61	56.59 ± 7.27	23.03 ± 5.57
VT (% $\dot{V}O_{2max}$)	77.0 ± 4.61	77.37 ± 5.43	70.07 ± 11.00

VT, ventilatory threshold.

METHODS

Study 1 participants. Thirty physically active volunteers (14 women, 16 men) were recruited from the student population of a major university. Participant characteristics are shown in Table 1. Each participant read and signed an informed consent form that was approved by the university's institutional review board. Each also signed a form certifying that he or she had been given a physical examination during the previous year that had revealed no contraindications to vigorous physical activity. In addition, before testing, all participants completed the Physical Activity Readiness Questionnaire (21) and, having given negative responses to all the questions, were deemed apparently healthy.

Study 2 participants. As explained in the Results section below, study 1 showed that the correlation between tolerance and post-VT test duration was somewhat stronger among women than in men, although not to a statistically significant degree. Although this certainly does not constitute conclusive evidence of a gender difference, it was deemed prudent to control for gender in this follow-up study by focusing on an all-female sample. An initial sample of 50 women expressed interest in the study. These women were screened by a telephone interview to ensure that (a) according to a 7-d physical activity recall interview (1), they expended less than the recommended 200 kcal (16) or participated in less than 30 min of moderate physical activity per day on most days of the week (22), (b) they had not changed their physical activity habits during the past 12 months (and, thus, according to the 7-d physical activity recall, they were sedentary), (c) they had been given a physical examination during the previous 12 months that had revealed no contraindications to vigorous physical activity, (d) they were apparently healthy according to the Physical Activity Readiness Questionnaire (21), (e) they were not suffering from any injuries or other ailments, and (f) they were nonsmokers. After this initial screening, 27 women were scheduled for testing. Of these, three terminated the incremental treadmill test prematurely because of skeletal or muscular complaints (see the Procedures section below), leaving a final sample of 24. Participant characteristics are shown in Table 1. Before their involvement in the study, all participants read and signed an informed consent form approved by the university's institutional review board.

Study 1 measures. The PRETIE-Q was used to assess the variables of preference for and tolerance of exercise intensity. The eight-item preference scale contains four items that tap preference for high intensity (e.g., "I would rather have a short, intense workout than a long, low-intensity workout") and four that tap preference for low intensity and are reverse-scored (e.g., "When I exercise, I usually prefer a slow, steady pace"). The eight-item tolerance scale contains four items that tap high exercise tolerance (e.g., "I always push through muscle soreness and fatigue when working out") and four that tap low exercise tolerance and are reverse-scored (e.g., "During exercise, if my muscles begin to burn excessively or if I find myself breathing very hard, it is time for me to ease off"). Each item is accompanied by a five-point response scale ranging from "I totally disagree" to "I totally agree." Thus, preference and tolerance scores range from 8 to 40. The complete questionnaire is available in an article by Ekkekakis et al. (6). Alpha coefficients of internal consistency have been reported to range between 0.81 and 0.85 for the preference scale and between 0.82 and 0.87 for the tolerance scale (6). Furthermore, test–retest reliability coefficients have been reported as 0.67 and 0.80 for the preference scale and as 0.85 and 0.72 for the tolerance scale, after 3- and 4-month intervals, respectively (6). Although the focus in this study was on the tolerance scale, the preference scale was also examined to provide a test of the discriminant validity of these scales. Specifically, it was predicted that the scores on the tolerance scale would emerge as stronger predictors of post-VT test duration than the scores on the preference scale.

Self-reported habitual intensity of physical activity was assessed by a modified form of Borg's (2) Category Ratio 10 Scale, with the same scale and anchors as the original but referring to the intensity of habitual physical activity rather than an ongoing bout of physical activity. Frequency of habitual physical activity was assessed by the question, "How many days (on average) do you exercise per week?" (in days). Habitual session duration was assessed by the question, "How long (on average) do you exercise per session?" (in minutes). Overall duration of lifetime involvement was assessed by the question, "How long have you been exercising on a regular basis (at least three times per week, 20+ min per session)?" (in years and months, later converted to months).

$\dot{V}O_2$ and $\dot{V}CO_2$ were analyzed online with a metabolic analysis system (OCM-2, AEI Technologies, Pittsburgh, PA). The system consisted of an O_2 analyzer (S-3A/I, Ametek Applied Electrochemistry, Sunnyvale, CA), a CO_2 analyzer (CD-3A, Ametek Applied Electrochemistry), and a turbine volume-measurement system. Expired gas was sampled from a 4.2-L mixing chamber with every breath. The analyzers were connected to a computer via an analog-to-digital converter, and Respiratory Response Data Acquisition System software (version 3.51, Physio-Dyne, Massapequa, NY) was used to collect and store the data. The gas analyzers were calibrated before each test.

Study 2 measures. Preference for and tolerance of exercise intensity were assessed with the PRETIE-Q (6), as described in study 1.

$\dot{V}O_2$ and $\dot{V}CO_2$ were assessed with an open-circuit computerized metabolic analysis system (TrueMax 2400, ParvoMedics, Sandy, UT). The system consists of an O_2 analyzer, a CO_2 analyzer, and a screen pneumotachometer (model 3813, Hans Rudolph). Expired gas was sampled from a 4.0-L mixing chamber with every breath. The analyzers were connected to a computer via an analog-to-digital converter, and Consentius Technologies OUSW-3.3 software (Salt Lake City, UT) was used to collect and store the data. The gas analyzers were calibrated before each test.

Study 1 procedures. Before the experimental session, each participant was instructed to abstain from consuming alcoholic beverages, exercising on the day of testing, and eating for 4 h before testing. On arrival at the laboratory, each participant was given a detailed description of the procedures to be followed during the graded treadmill test. Subsequently, each participant was fitted with a heart rate transmitter (Polar Electro Oy, Kempele, Finland) and a face mask equipped with an ultralow-resistance, two-way, nonrebreathing valve (model 2700, Hans Rudolph). After ensuring the proper fit of the mask, the participant was shown to the treadmill (Q55xt series 90, Quinton, Seattle, WA). Expired gases were collected for 2 min while the participant was seated, to ensure the proper functioning of the various components of the metabolic analysis system. After a 5-min warm-up walk (4.8 $km \cdot h^{-1}$, 0% incline), the workload was increased in 1-min stages by alternating between increases in speed by 0.8 $km \cdot h^{-1}$ or incline by 1%, starting with an increase in speed. The increases in workload were continued until each participant reached the point of volitional exhaustion (i.e., terminated the test by pressing a button). All participants satisfied at least two of the following criteria for reaching maximal capacity: (a) reaching a plateau in oxygen consumption (change of less than 2 $mL \cdot kg^{-1} \cdot min^{-1}$ after an increase in workload), (b) attaining a respiratory exchange ratio equal to or higher than 1.1, or (c) reaching or exceeding age-predicted maximal heart rate (i.e., 220 − age).

In subsequent offline analyses, the highest 30-s average value of $\dot{V}O_2$ attained was designated as $\dot{V}O_{2max}$. Likewise, the average $\dot{V}O_2$ associated with the 30-s period during which the VT occurred was designated as VT.

The VT was determined offline by a computerized version of the three-method combined procedure proposed by Gaskill et al. (7). Specifically, the following methods were used: (a) the V-slope (i.e., plotting CO_2 production over O_2 use and identifying a breakpoint in the slope of the relationship between these two variables), (b) the method of the ventilatory equivalents (i.e., plotting the ventilatory equivalents for O_2 ($\dot{V}_E/\dot{V}O_2$) and CO_2 ($\dot{V}_E/\dot{V}CO_2$) over time and identifying the level of exercise intensity corresponding to the first rise in $\dot{V}_E/\dot{V}O_2$ that occurs without a concurrent rise in $\dot{V}_E/\dot{V}CO_2$), and (c) the excess CO_2 method (i.e., plotting excess CO_2 over time and identifying the level of exercise intensity corresponding to an increase in excess CO_2 from steady state). All data were converted to 20-s averages before analysis. The VT was determined to occur at the point where at least two of the three methods converged or, if this was not feasible, the point that produced the lowest mean square residual from a two-segment piecewise regression analysis. The solution was verified by visual inspection after plotting regression lines through the pre- and postbreakpoint data segments.

Study 2 procedures. Before the experimental session, each participant was instructed to abstain from consuming alcoholic beverages, exercising on the day of testing, and eating for 4 h before testing. On arrival at the laboratory, each participant received a detailed description of the procedures to be followed during the graded treadmill test.

After signing the informed consent form, each participant was fitted with a heart rate transmitter (Polar Electro Oy, Kempele, Finland) and a face mask (model 8920/30, Hans Rudolph). Two minutes of resting data were collected while the participant was standing on the belt of the treadmill (L8, Landice, Randolph, NJ), to ensure the proper functioning of the components of the metabolic analysis system. Given that the participants were chronically sedentary, no separate warm-up period was given, to prevent the accumulation of fatigue and rapid exhaustion during the incremental phase of the test. Instead, the incremental protocol began from a very low workload, at a speed of 4 km·h^{-1} and 0% grade for 2 min. Thereafter, the speed was increased by 0.64 km·h^{-1} every second minute (while maintaining the grade at 0%) until each participant reached the point of volitional exhaustion. As noted earlier (see Participants section), 3 of the 27 women terminated the test during its early stages (before the VT) because of muscular and skeletal complaints (i.e., knee pain, perceived weakness in the legs). These three women were excluded from further analyses. $\dot{V}O_{2max}$ and VT for the remainder of the sample were determined by the same procedures outlined for study 1. Given the lack of recent exercise experience among these participants, it would not have been possible for them to provide meaningful responses to the questions of the PRETIE-Q, which inquire about usual responses during exercise. Consequently, they completed the PRETIE-Q an average of 14 d later. During this period, they had the opportunity to exercise twice under supervision in the laboratory, as well as on additional occasions on their own in the field.

RESULTS

Study 1 results. The exercise test lasted for 12.48 ± 3.06 min (range 5.65–18.70 min). Volitional exhaustion occurred 6.04 ± 1.29 min (range 4–9 min) after the individually determined VT. Tolerance correlated significantly with overall test duration (r = 0.44, P = 0.01, 95% CI = 0.09–0.69), $\dot{V}O_{2max}$ (r = 0.46, P = 0.01, 95% CI = 0.12–0.70), and duration after the VT (r = 0.43, P = 0.02, 95% CI = 0.08–0.68). Although correlational statistics based on samples smaller than 30 should be viewed cautiously, it is worth pointing out that the relationship between tolerance and duration after the VT seemed somewhat stronger among women (r = 0.49) than men (r = 0.24), but this difference was not statistically significant (Fig. 1). Men and women did not differ significantly in terms of tolerance (t = 1.34, P = 0.19, 95% CI = −6.45 to 1.34), preference (t = 1.68, P = 0.11, 95% CI = −7.71 to 0.79), or duration after the VT (t = 1.93, P = 0.06, 95% CI = −1.80 to 0.05). As expected, they did differ in terms of the total duration of the test (t = 3.25, P = 0.00, 95% CI = −5.15 to −1.17) and $\dot{V}O_{2max}$ (t = 3.26, P = 0.00, 95% CI = −14.44 to −3.30).

The relationship between tolerance and duration after the VT did not persist once $\dot{V}O_{2max}$ (range 36.30–70.30 mL·kg^{-1}·min^{-1}) had been taken into account, because $\dot{V}O_{2max}$ exhibited substantial correlations, both with the duration after the VT (r = 0.44, P = 0.01, 95% CI = 0.09–0.69) and with tolerance. Specifically, the partial correlation was r = 0.28 (P = 0.13, 95% CI = −0.09 to 0.58) and the semipartial correlation was r = 0.25 (P = 0.18, 95% CI = −0.12 to 0.56). With $\dot{V}O_{2max}$ accounting for 18.9% of the variance in duration after the VT, the introduction of tolerance in a hierarchical regression analysis contributed only an additional 6.5% in explained variance (β = 0.29, F_{change} = 2.34, P = 0.14). However, the relationship between tolerance and duration after the VT did persist after controlling for age (range 18–27 yr), body mass index (range 18.60–27.78 kg·m^{-2}), self-reported frequency of habitual physical activity (range 1–7 d·wk^{-1}), and self-reported habitual duration of physical activity per session

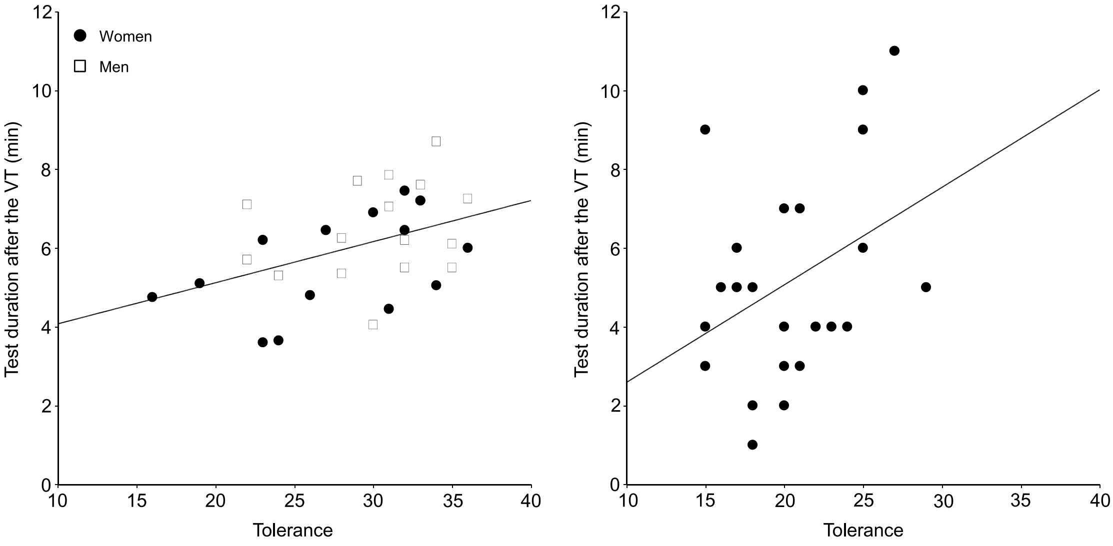

FIGURE 1—Scatter plots for the relationship between tolerance and duration after the ventilatory threshold in study 1 (*left*) and study 2 (*right*). *Lines* represent the lines of best fit for the entire sample.

(range 30–190 min). The combination of these four variables accounted for 12.6% of the variance in duration after the VT, whereas the inclusion of tolerance in the model accounted for an additional 14.0% ($\beta = 0.48$, $F_{\text{change}} = 4.58$, $P = 0.04$). The contribution of tolerance became marginally nonsignificant ($\beta = 0.49$, $R^2_{\text{change}} = 0.12$, $F_{\text{change}} = 3.88$, $P = 0.06$) when the intensity of habitual physical activity (ranging from 3 to 10, on a 10-point scale) was also entered into the equation (due to the decrease in the degrees of freedom; its contribution to the model remained essentially unaltered).

On the other hand, the significant bivariate relationship between tolerance and $\dot{V}O_{2max}$ did not persist after accounting for the four aforementioned variables. Combined, these variables accounted for 29.9% of the variance in $\dot{V}O_{2max}$ ($F_{\text{change}} = 2.66$, $P = 0.05$). The addition of tolerance in the model contributed only an additional 4.1% ($\beta = 0.26$, $F_{\text{change}} = 1.48$, $P = 0.24$).

The correlation between preference and tolerance was moderately positive ($r = 0.40$, $P = 0.03$, 95% CI = 0.05–0.66), consistent with a previous report (6). Although preference showed a significant bivariate relationship with duration after the VT ($r = 0.42$, $P = 0.02$, 95% CI = 0.07–0.68), this did not persist after accounting for age, body mass index, self-reported frequency of habitual physical activity, and self-reported habitual duration of physical activity per session. The inclusion of preference in the model contributed an additional 12.7% in explained variance ($\beta = 0.40$, $F_{\text{change}} = 3.77$, $P = 0.07$). Preference also did not correlate significantly with the total duration of the test ($r = 0.04$) or with $\dot{V}O_{2max}$ ($r = 0.12$).

Study 2 results. The exercise test lasted 13.58 ± 4.24 min (range 7–25 min). Volitional exhaustion occurred 5.13 ± 2.59 min after the VT, with individual values ranging from 1 to 11 min. In this sample, tolerance did not correlate with $\dot{V}O_{2max}$ ($r = -0.09$) or with the total duration of the test ($r = -0.11$). However, the bivariate correlation between tolerance and test duration after the VT approached statistical significance ($r = 0.38$, $P = 0.07$, 95% CI = −0.03 to 0.68; Fig. 1).

In a hierarchical regression analysis with the duration after the VT as the dependent variable, $\dot{V}O_{2max}$ (range 14.70–33.62 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) accounted for 40.8% of the variance ($\beta = 0.64$, $F_{\text{change}} = 14.46$, $P = 0.001$). Tolerance added 19.0% of unique variance ($\beta = 0.44$, $F_{\text{change}} = 9.42$, $P = 0.006$). When $\dot{V}O_{2max}$, age, and body mass index were introduced in the model, collectively accounting for 42.2% of the variance ($F_{\text{change}} = 4.63$, $P = 0.01$), tolerance still contributed an additional 20.0% ($\beta = 0.46$, $F_{\text{change}} = 9.50$, $P = 0.006$). Given the sedentary nature of this sample, there were no variables pertaining to habitual physical activity in this dataset.

The correlation between preference and tolerance was again moderately positive, albeit not significant ($r = 0.24$, $P = 0.26$, 95% CI = −0.18 to 0.59). Preference did not show a significant bivariate correlation with $\dot{V}O_{2max}$ ($r = 0.14$) or with the total duration of the test ($r = 0.20$). It did, however, correlate significantly with the duration after the VT ($r = 0.45$, $P = 0.03$, 95% CI = 0.06–0.72). This relationship persisted when the variance attributable to $\dot{V}O_{2max}$, age, and body mass index was controlled. The introduction of preference in the model contributed an additional 16.2% of explained variance ($\beta = 0.42$, $F_{\text{change}} = 7.00$, $P = 0.02$).

DISCUSSION

The concept of tolerance of exercise intensity has been defined as a trait that influences one's ability to continue exercising at levels of intensity associated with discomfort or displeasure (6). Recent studies have demonstrated that the level of exercise intensity at which pleasure ratings begin to decline is the level associated with the VT (5,11). Thus, in these studies, tolerance was operationally defined as the duration of exercise (expressed in minutes), during a graded treadmill test, for which individuals could persist beyond their individually determined VT. To our knowledge, this is the first investigation into the role of self-reported individual differences in exercise intensity tolerance.

In study 1, tolerance did correlate, as hypothesized, with the amount of time individuals persevered beyond the point at which they reached their VT. Importantly, the relationship persisted even after controlling for age, body mass index, self-reported frequency of habitual physical activity, and self-reported habitual duration of physical activity per session. Tolerance accounted for 14% of additional variance in post-VT test duration beyond the 12.6% accounted for jointly by these four variables. However, the relationship between tolerance and post-VT test duration was not independent of cardiorespiratory fitness. Both tolerance and post-VT test duration correlated significantly with $\dot{V}O_{2max}$. Thus, among the physically active participants in this sample, because tolerance and $\dot{V}O_{2max}$ shared a substantial amount of common variance, once $\dot{V}O_{2max}$ was entered in the model, there was not an opportunity for tolerance to account for added variance. What this finding seems to indicate is that tolerance might be related to exercise test duration after the VT both directly (i.e., by influencing a person's perseverance against aversive bodily symptoms) and indirectly (i.e., by predisposing an individual to exercise more and, thus, improve his or her fitness). In this sample, tolerance correlated significantly with both the frequency ($r = 0.47$, $P = 0.009$, 95% CI = 0.13–0.71) and the intensity ($r = 0.45$, $P = 0.01$, 95% CI = 0.11–0.70) of habitual physical activity. In turn, frequency ($r = 0.48$, $P = 0.007$, 95% CI = 0.14–0.72), but not intensity ($r = 0.12$), was correlated with $\dot{V}O_{2max}$.

Unlike the participants in study 1, the participants in study 2 were chronically sedentary. Consequently, the possible indirect influence of tolerance on the duration after the VT through $\dot{V}O_{2max}$ was eliminated. Furthermore, although both $\dot{V}O_{2max}$ ($r = 0.63$, $P = 0.001$, 95% CI = 0.30–0.82) and, to some extent, tolerance ($r = 0.38$,

$P = 0.07$, 95% CI = −0.03 to 0.68) were related to post-VT test duration, they did not relate to each other ($r = -0.09$). This pattern of interrelationships suggests that tolerance can be associated with post-VT test duration independently of cardiorespiratory fitness, complementing the findings from study 1. With $\dot{V}O_{2max}$, age, and body mass index in the model, tolerance accounted for an additional 20% of the variance in post-VT test duration.

These findings may be of potential interest to clinicians. As noted in the introduction, exercise tolerance tests are usually terminated by the patients themselves because of subjective symptoms such as exhaustion or pain. Thus, the efficacy of the test as a diagnostic or prognostic tool depends, to a certain extent, on the resilience that different individuals exhibit for the bodily symptoms induced by strenuous exercise. The data presented here show that the tolerance scale of the PRETIE-Q could offer a measure of this resilience. Using the time after VT as a criterion, the tolerance scale accounted for 14–20% of the variance beyond what was accounted for by age, body mass index, and self-reported frequency and duration of habitual physical activity (study 1) or age, body mass index, and $\dot{V}O_{2max}$ (study 2). Thus, the tolerance scale of the PRETIE-Q could be used in combination with other variables to develop a protocol for screening individuals who might be predisposed to terminate a test prematurely or to persist despite the emergence of warning signs (e.g., chest pain or discomfort). Certainly, this would be a long-term research effort. Perhaps the most important (and also the most challenging) step would be the establishment of criteria for what constitutes under- and overexertion in various patient populations.

The data presented here add to the body of evidence supporting the construct validity of the tolerance scale of the PRETIE-Q, as well as the discriminant validity of the tolerance and preference scales. In the two studies described here, the tolerance scale was found to be related to the amount of time for which individuals persevered during a graded treadmill test beyond their VT. This new evidence is important because the predictor (i.e., tolerance) and the criterion (i.e., duration after the VT) do not share common method variance, as was the case with the previously published validation data (i.e., both tolerance and pleasure–displeasure being self-reported). Moreover, although tolerance and preference were moderately related (as in previous reports (6)), there was evidence of discriminant validity. Like tolerance, preference showed significant bivariate relationships with the duration after the VT in both studies (r = 0.42 and 0.45, respectively). However, once other variables had been taken into account, the relationship either did not persist (study 1) or was somewhat weaker than the relationship with tolerance (study 2; 16.2% of explained variance compared with 20.0%).

A promising area for future inquiry involves the exploration of the neuroanatomical and neurophysiological basis of the individual differences in exercise intensity tolerance. Given the remarkable magnitude of these differences and their impact on clinical assessments, it is surprising that essentially nothing is presently known about the brain mechanisms involved. As with many other behavioral traits that show large variance, the common assumption is that these differences are partly attributable to "nature" (i.e., genetically determined traits) and partly attributable to "nurture" (e.g., acquired fear and, possibly, several other cognitive, social, and cultural factors). In the postgenomic era, the exploration of the genetic factors, in particular, seems an extremely intriguing prospect. The genetic bases of individual differences in pain sensitivity and tolerance have been the focus of scientific investigation for a long time and could serve as a useful blueprint. Like pain tolerance, the tolerance of exercise intensity is believed to show heritable variation, because it essentially offers a trade-off between potential benefits and risks. Thus, its effects remain "neutral" from an adaptational standpoint on the population level (were it consistently advantageous or consistently harmful, the variation would have been gradually eliminated). Being able to tolerate bodily symptoms elicited by strenuous exercise would, on the one hand, offer the ability to cover longer distances (or under more adverse environmental conditions) in search of resources and mates. On the other hand, it also could bring one dangerously close to his or her biological limits (e.g., exposing one to increased risk of exhaustion, heat stroke, or cardiac death).

Several authors have recently drawn attention to other commonalities between the systems responsible for pain (particularly visceral pain) and responses to homeostatic perturbations, such as those elicited by strenuous exercise (17). On the basis of emerging evidence, it seems appropriate to highlight the possible role of central opioid receptors (particularly mu (17)) and dopamine receptors (particularly D2 (10)). Central opioids (18) and dopamine (24) both are involved in the brain response to exercise. A role for the former (19,20) and, possibly, for the latter (23) has also been shown in human exercise tolerance. A recent study on human pain also suggests that the two systems might be functionally linked (25).

In interpreting the results of the present studies, readers should take into account their inherent limitations. Primary among these is the fact that these were correlational studies that involved relatively small samples. Correlational statistics tend to be relatively labile, so the stability and generalizability of estimates are generally improved with larger samples. Nevertheless, it is worth pointing out that we did find consistent results across two diverse samples (i.e., young and physically active vs middle-aged and chronically sedentary). Secondly, both samples consisted of apparently healthy individuals. Therefore, direct extrapolations of the findings reported herein to clinical samples are unwarranted at this stage. This is particularly important because, in these studies, we operationalized tolerance as the duration of the exercise test after the VT. The presence of an exercise-limiting condition (e.g., cardiovascular disease, intermittent claudication, chronic obstructive pulmonary disease, asthma, osteoarthritis) clearly would necessitate a different operational definition (possibly, the period of time between symptom onset and exercise termination). Finally, it should be noted that the PRETIE-Q was administered to participants in study 2 an average of 14 d after the exercise test. This was deemed necessary because of the complete lack of recent exercise experience in this chronically sedentary sample. However, it should be acknowledged that the assessment of both tolerance and preference at that time could have been influenced by the unique challenges experienced by formerly sedentary adults who were just beginning to exercise again.

In conclusion, we have shown, in two studies, that self-reported tolerance of exercise intensity, measured by the tolerance scale of the PRETIE-Q, was associated with the period of time that healthy individuals persisted during incremental treadmill tests after having reached their VT. This relationship remained significant after age, body mass index, and self-reported frequency and duration of habitual physical activity (study 1) or after age, body mass index, and $\dot{V}O_{2max}$ (study 2) had been taken into account.

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